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Review Article

Surgery of the turbinates and "empty nose" syndrome

Abstract

Surgical therapy of the inferior and/or middle turbinate is indicated when conservative treatment options have failed. The desired goal is a reduction of the soft tissue volume of the turbinates regarding the individual anatomic findings, whilst simultaneously conserving as much mucosa as possible. As the turbinates serve as a functional entity within the nose, they ensure climatisation, humidification and cleaning of the inhaled air. Thus free nasal breathing means a decent quality of life, as well.

Regarding the multitude of different surgical techniques, we confirm that no ideal standard technique for turbinate reduction has been developed so far. Moreover, there is a lack of prospective and comparable long-term studies, which makes it difficult to recommend evidence-based surgical techniques. However, the anterior turbinoplasty seems to fulfil the preconditions of limited tissue reduction and mucosa-preservation, and therefore it is the method of choice today.

Radical resection of the turbinates may lead to severe functional disturbances developing a secondary atrophic rhinitis. The "empty nose" syndrome is a specific entity within the secondary atrophic rhinitis where intranasal changes in airflow result in disturbed climatisation and also interfere with pulmonary function. Results deriving from an actual in vivo study of climatisation and airflow in "empty nose" patients are presented.

Keywords: inferior turbinate, middle turbinate, turbinate surgery, laser surgery, pediatric surgery of turbinates, "empty nose" syndrome

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1 Introduction

"To be successful, intranasal operations must be so designed as to restore the normal physiologic function of the nose. It is impossible with impunity to operate upon the interior of the nose as though it were simply an air flue and on the sinuses as though they were boxes."
Anderson C. Hilding, 1950

Beside septal deviation, enlarged turbinates are the second most frequent cause of obstructions to nasal breathing [1].

Chronic obstruction of nasal breathing can interfere with social and business activities and can thus considerably compromise quality of life [2].

Turbinates can be enlarged as a result of physiological, pathophysiological or anatomical reasons. In this context we deliberately do no not talk exclusively about a hyperplastic turbinate, as it is not always a case of a genuine hyperplasia of the turbinate mucosa.

Nasal mucosa, in particular of the inferior turbinate, are subject to a change in degrees of swelling lasting 3–4 hours during the course of a day, depending upon the nasal cycle. This has been known since the end of the 19th century, however its actual function has not yet been fully explained. Eccles surmises that on swelling of the mucosa, muscles surrounding the venous capacity vessels are contracted in order to express immunoglobulin (IgA and IgB) and mediators. This supports the thesis of the nasal mucosa's humoral defences against infections [3], [4].

In the literature, details on the frequency of the nasal cycle in healthy people differ. Maran and Lund assume that the nasal cycle is found in around 80% of the population and occurs subjectively unnoticed as the endonasal resistance remains constant. Eccles and coworkers were able to verify the nasal cycle in 20–40% of healthy adults. The cycle is adrenergic-stimulated. It is suspected that the activity of the sympathetic nerve is subject to changes which are regulated via the respiratory centre in the brain stem and which are closely associated with breathing activity [5], [6].

A further physiological variation of an enlarged turbinate is the compensatory increase in volume on the concave side of a septum deviation, whereby a narrow space is formed. This allows for a natural normalisation of the respiratory function. Based on rhinoresistometric measurements on a detumesced, compensatory enlarged turbinate, Mlynski was able to illustrate that although turbulence increased, the cross-section of the air space remained unchanged [7].

Every pathological process which leads to swelling of the nasal turbinates also normally causes a nasal obstruction. The reason for this is the particular anatomy of the nasal

valve area which is the narrowest point of the nose. As well as the cartilaginous septum and the caudal edge of the lateral cartilage, it is above the head of the lower turbinate which carries out this change in volume so dynamically. The most frequent causes of this mucosal dysregulation are the allergic or vasomotor rhinitis [8].
However, chemical and physical toxins, anti-cholinergic medication, hormonal disorders, systemic diseases and acute and chronic inflammation can be responsible for mucosal swelling. A detailed summary is given in Tasman [1].
To be seen apart from this are the purely anatomically conditioned enlargements of the inferior and middle turbinates. As the inferior turbinate has its own ossification centre, which is formed roughly in the 5th embryonic month, the bone density of the os turbinale varies considerably [9]. This osseous hyperplasia can cause a marked contraction of the endonasal airway. In about one third of the population, the middle turbinate is pneumatised, the so-called concha bullosa.

2 Anatomy and physiology of the turbinate

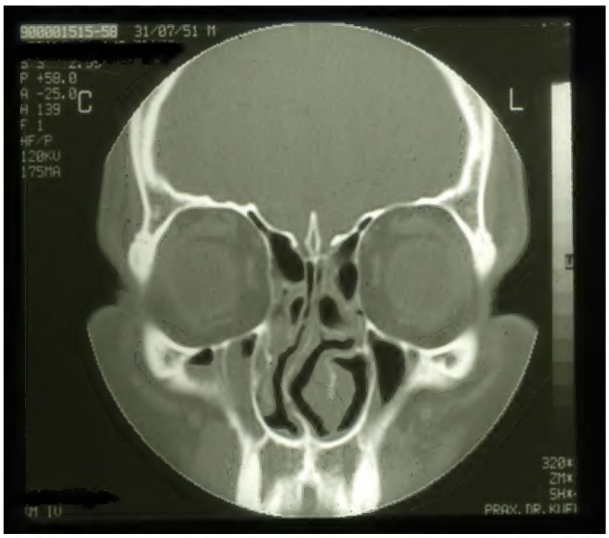

Figure 1: Coronary paranasal sinus computer tomography. Pronounced angled variants of the left os turbinale with simultaneous hypertrophy as a result of the convex deviation of the septum. Sinusitis maxillaris et ethmoidalis, right.

The inferior turbinate (concha nasalis inferior) is the largest of all turbinates. Its length, on average is 48.7 mm in men, and 47.3 mm in women. For clinical-physiological as well as surgical reasons, the turbinate is divided into head, body and rear end. It is composed of the os turbinale, the covering mucoperiosteum, an extensive plexus of venous capacity vessels and the respiratory mucosa. The os turbinale is slightly rolled and inserted in the middle maxillary wall partly at substantially varying angles of between 20° and 90° (Figure 1). It also has connections to the os lacrimale, the os ethmoidale and the os palatinum and forms in part of the ductus nasolacrimalis. The arterial blood supply passes through the A. sphenopalatina.
The middle turbinate (concha nasalis media) is a part of the os ethmoidale, and is in contact with the lamina cribrosa in a superior directed position. In the area of the turbinate head, the arterial blood supply passes through the A. ethmoidalis anterior, the rear turbinate end is supplied by the A. sphenopalatina [9], [10].
The osseous skeleton of the turbinates can be structured in different ways. The lamellar bone formation can be found most frequently, particularly with the inferior turbinate. The bone can also be spongious and reminiscent of the formation of the perpendicular plate in the anterior section. Both the inferior and the middle turbinate have this bone structure. The bullous, mustered bone can typically be found in the middle turbinate (concha bullosa, see above), a bullous inferior turbinate is rare. To date, only 11 cases worldwide have been published [11].
The concha bullosa is also lined on the inside with mucosa and drains through its own natural ostium into the infundiblum ethmoidale. Due to its many septums and chambers, it can achieve a substantial size, and can lead to an obstruction on contact with the septum and/or the infundibulum. The mucosa and the cavernous parenchyma are less voluminous than it is the case with the inferior turbinate [12]. The strongly vascularised mucosa plays an important part in humidifying air and in purifying inspired air [13].
The mucosa covers a surface of about 100–200 cm^2. In the submucosa of the respiratory epithelium, alongside serosal glands there are also mucous-secreting goblet cells. In contrast to the middle turbinate, the number of goblet cells in the inferior turbinate is significantly raised. The highly prismatic, kinocilia-carrying cells (ciliated cells) responsible for mucociliary clearance are integrated into the multiple row epithelium, and are broad-based connected to the basal membrane [14].
The venous capacity vessels (sinusoids) are subepithelially localised in the lamina propria of the inferior and middle turbinates. They are significantly involved in the regulation of the thickness of the mucosa. In a swollen condition, the volume of the inferior turbinate can increase by 3 to four times compared with its subsided state, and can then almost completely block the lower nasal passage. The control of the blood supply to the mucosa takes place via arterial resistance vessels which are sympathtically innervated. Both the resistance vessels and the sinusoids are surrounded by adrenergic nerve fibres, so that an increased sympathicotonus leads to a decongestion of the mucous membrane [15], [16], [17].
In a supine position with a rise in CO_2 or an inhalation of cool air, the volume of the capacity vessels increases [18], [19], [20]. Interestingly enough, the capacity vessels of the inferior turbinate are more numerous than in the middle turbinate [21].
This, and the anatomy of the nasal valve described above, establishes the significance of the state of swelling in the inferior turbinate as a decisive regulator for nasal respiratory resistance. The inhaled air striking the head of the

middle nasal concha is spread as a turbulent flow on the mucous membrane in the middle and posterior areas of the nose (diffusor) [22]. Simultaneously the nasal respiratory resistance proportionately regulates the pulmonary flow of blood (resistor) [23].

3 Diagnostics

Before planning and implementing a therapy procedure for the treatment of obstructed nasal breathing, careful diagnostics is of prime importance. After taking the medical history, the nose should be examined both internally and externally. Following an anterior rhinoscopy, a rigid endoscopy is performed in order to evaluate the extent of the enlargement of the concha. At the same time, other causes of obstructed nasal breathing can be recognised, for example a deviated septum or a polyposis nasi. A posterior rhinoscopy with a transorally inserted 70° endoscope for the clearance of adenoids or other pathological changes completes the examination. It is recommended to repeat the endonasal diagnostics with an α-sympathomimetic after a 10 minutes decongestion of the mucous membrane. Jones and his research team were able to demonstrate that there was a good correlation between the subjectively experienced improvement in nasal breathing following decongestion and the objectifiable success of the therapy [24].
A further advantage of this approach is that it can be clarified before therapy whether a thickening of the mucosa membrane or a protrusion of the os turbinale is responsible for the nasal obstruction.
In order to exclude an allergic rhinitis, at least an intracutaneous prick test should be carried out before any operation on the turbinates and/or the septum. A positive testing for corresponding inhalant allergens can spare patients an unnecessary operation on the turbinates and an operative failure [25].

3.1 Apparative diagnostics

Today, thanks to the enormous progress made in measurement and control technology, the examination of the flow of air through the nose and the assessment of the minimal sectional area in the nose have attained a very high standard. Nevertheless, the data collected do not always correspond to the subjective experience of the patient. Cole had already pointed out this problem in 1989. According to him, in case of about 20% of patients suffering from an obstruction of nasal breathing, the rhinomanometrically measured nasal impedance in comparison to the general population was normal or reduced [26], [27].
In the context of the preoperative assessment of nasal impedance, two procedures in clinical routine diagnostics have been established.

3.1.1 Active anterior rhinomanometry

With active anterior rhinomanometry, the differential pressure is recorded between the nostrils and the posterior apertures of nose and the volume of the air flow separately for both nostrils. In this way, an increase in nasal impediment can be registered, but not the localisation of the intranasal pathology. By measurement before and after the administration of a decongestant α-adrenergic sympathomimetic it can at least be estimated just how far the proportion of mucosa membrane swelling or a deviated nasal septum is decisive for a nasal obstruction. Three further disadvantages of the procedure are mentioned here: 1. The values of individual appliances differ considerably in part from each other. 2. Stable values can only be achieved through the patient's regular breathing. 3. In the case of septal perforations, rhinomanometry cannot be used for procedural purposes [28], [29]. The measurement of the severity of subjectively obstructed nasal breathing is, therefore, only possible on a semi-objective basis. Understanding that the rhinomanometry only allows general propositions about nasal impediment, it is still an important diagnostic instrument, above all in combination with acoustic rhinometry.

3.1.2 Acoustic rhinometry

Acoustic rhinometry allows the measurement of mostly all nasal sections volumes. The principle of this acoustic reflexion technique is based upon the measurements of acoustic signals which are introduced into the upper airways as clicks of 0.2 ms duration with 120–130 dB, and which are then again reflected by anatomical components. The reflected signals are picked up in a range of between 0.1 and 10 kHz. This enables a reliable topodiagnostic of anterior intranasal constriction. Hilberg and colleagues were the first to implement this method in the nasal area [30].
The differentiation between "mucosa membrane factor" and other constriction can be determined by use of acoustic rhinometry before and after decongestion.
The advantage of this procedure is its objectivity and good reproducibility. It is quick and non-invasive, which is of particular value in the rhinological examination of children. There are diagnostic limits, however. As sensitivity decreases with increasing depth of penetration, only the nasal valve area and the anterior sections of the nose can be checked reliably. Pathological findings in the posterior regions and in the nasopharynx cannot be registered. Constrictions behind stenoses will not be discovered; even with perforations of the septum no reliable values can be expected. The dynamic phenomenon caused by the collapse of the nasal valve cannot be detected by acoustic rhinometry.

3.1.3 Rhinoresistometry

In rhinoresistometry, resistance curves are recorded which reveal information on the flow characteristics on

the inside of the nose. The method enables to distinguish between either structural obstructions to nasal breathing or those caused by swelling. The inspiratory and expiratory resistance depending on the volume velocity are measured with the aid of a computer before and after decongestion, and entered in a diagram. It is not possible to draw direct conclusions about the conditioning function of the nose. The examination process corresponds to rhinomanometry and is therefore semi-objective [31].
The following procedure based upon diagnostics is mentioned here for the sake of completeness, but is not used in clinical applications and remains the subject of scientific questioning.

3.1.4 Rhinostereometry

With the help of rhinostereometry, smallest changes (<0.2 mm) in the degree of swelling of the inferior turbinate can be microscopically recognised, as, for example, with the nasal provocation in allergy diagnostics or with the use of rhinological agents [32].
The diagnostic procedures described, in particular active anterior rhinomanometry and acoustic rhinometry, should have an orientative role with the indication for surgical procedures and should be applied subordinately in decision-making. What is of importance is the positive correlation of the patient's physical complaints with the pathology found by the rhinological examination (stenosis of the nostrils, enlargement of the turbinates, deviated nasal septum, nasal valve collapse etc.).

4 Variants of turbinate pathology

In order to treat changes in the inferior and middle turbinates effectively, it is first useful to differentiate between pathological variants [33].

4.1 Inferior turbinates

4.1.1 Compensatory hypertrophy

Compensatory hypertrophy is a frequent "pathological" entity and in connection with a c-shaped deviation of the nasal septum always appears on the side of the broadest main nasal cavity. Paradoxically, it is therefore a physiological reaction towards a pathology of the septum, as the hypertrophy of the inferior turbinate narrows the excessively wide air space and thus normalises aerodynamics. Based on the results of their prospective, randomised studies, Grymer and Illum argue that compensatorily enlarged turbinates should be reduced in the case of a prominent deviation of the nasal septum. With a minor deviated nasal septum, a simultaneous reduction of the turbinate produced no improved functional results. It should be discussed whether in this specific case a reduction of the turbinate is in fact necessary, or whether a strategy of "wait and see" if a physiological correction of the turbinate following medialisation of the septum may not make more sense [34], [35].

4.1.2 Protrusion of the os turbinale

Median displacement of the os turbinale is a rare occurrence which can be diagnosed on the one hand by an exact rhinoscopy before and after decongestion, or even better with the help of a computer tomography. The angle between the lateral nasal wall and then os turbinale can be up to 90° so that the inferior turbinate extends further into the nasal lumen than usual (Figure 1).

4.1.3 Isolated hyperplasia of the inferior turbinate head and hyperplasia of the entire turbinate

In patients suffering from an allergic seasonal or perennial rhinopathy or vasomotoric rhinitis, an isolated hyperplasia of the head of the inferior turbinate can be observed. The mucosal oedema moves the head of the turbinate towards anterior-medial and shifts itself into the nasal valve area.
In addition to this the mucosal membrane of the whole turbinate can also be altered. In a prospective, controlled morphometric examination, Ophir's research group found that in contrast to the lateral mucosal area, the medial mucosa was more strongly thickened. The difference was scarcely significant. It was remarked in a histological context that the sinusoids in particular were significantly enlarged, and thus were primarily involved in the degree of swelling [36].
With regard to conservative therapy, see the relevant specialist literature [37], [38].

4.1.4 Hyperplasia of the end of the turbinate

An enlarged turbinate rear end is frequently caused by chronic sinusitis. The chronic inflammatory condition leads to hyperplasia of the mucosa and submucosa, which presents morphologically as papillomatous or polypoid formation of new tissue.

4.2 Middle turbinate

Changes of the middle turbinate can be classified either as normal anatomical variants or as true pathological variants.
The most frequent anatomical variant is the concha bullosa. With respect to the proportion and localisation of the pneumatisation, three different types can be distinguished: 1. lamellar type (pneumatisation of the vertical lamella), 2. bulbous type (pneumatisation of the inferior section), 3. expanded type (combination of types 1 and 2) [39].
The concha spongiosa, the paradoxically curved concha and the redundant concha are rare.
The concha polyposa is to be regarded as pathological and is most often encountered in the context of chronic

rhinosinusitis. The aetiology can be understood in the terms of a vitious circle: inflammation – mucosal oedema – polypoid turbinate degeneration – drainage obstruction – inflammation.

5 Therapy of the inferior turbinate

As outlined above, not every pathological enlargement of the turbinate indicates the necessity for surgery. Only an exact clarification of the cause of an obstruction to nasal breathing can ensure that the patient enjoys success from treatment for as long as possible. The main reason for therapeutic failure in turbinate surgery is less due to the operating technique as to the postoperative persisting multi-factorial mucosal membrane dysregulation [40].
With the exception of the compensatory turbinate hyperplasia, a surgical reduction of the turbinate should only be indicated if a three-month conservative therapy has not had any subjective and objective (active anterior rhinomanometry, acoustic rhinometry) success. If, for example, a subacute or chronic rhinosinusitis is present, the conservative treatment period should be extended to six months. In this case the topically and/or systemically applied antiphlogistic therapy should be supported by an antibiotic therapy.
In recent studies there has been a consensus on the primary conservative therapy and the point of surgical intervention [8], [41], [42], [43], [44], [45].
The main aim of turbinate surgery has to be the preservation of a well-functioning mucosa membrane, whilst at the same time creating a sufficiently large air space to ensure the humidification and purification of air and the maintenance of a physiological airway resistance.
In a comprehensive review, Mol and Huizing described 13 different surgical techniques for turbinate reduction [23]. This is reminiscent of the numerous surgical variants for the correction of protruding ears whose international publications number more than 100 [46].
The fact that several methods for turbinate reduction are used clearly demonstrates that there is apparently no ideal technique which guarantees long-term therapy success, but which is rather linked with short- and/or long-term complications [47].
In 2001, the Oxford Centre for Evidence-based Medicine published four different evidence levels from 1 (best) to 5 (worst), and four levels of recommendation from a (highest) to d (lowest) [48]. For surgical interventions, a maximum evidence level of 2 (i.e. prospective, comparative clinical study with different operative procedures and sufficient number of patients), for example, can be achieved. In accordance with these criteria, studies on turbinate surgery only meet the requirements of the evidence levels 3 and 4. Only two studies have as yet achieved evidence level 2; in these instances long-term follow-ups were conducted (Passali et al. 2003: long-term follow-up period 6 years, Joniau et al. 2006: long-term follow-up period 5 years). For turbinate surgery in childhood the criterion of follow-up following completion of growth should be added. No study has yet fulfilled this follow-up criterion [42].
In the literature referred to in the following therefore evidence-based recommendations cannot be assumed. Maran et al. pointed this out as early as 1997 when they examined 5 well-known oto-rhino-laryngology journals with regard to evidence-based recommendations. It was revealed that only 0.7 to 4% of all studies were randomised and controlled [49].
Succeeding technologies are no longer recommended today due to dangerous side effects or lack of therapeutic success: Vidian neurectomy, the injection of corticosteroids or sclerosing substances and chemo-coagulation [23].
In order to systemise the different surgical techniques, a division into 3 groups seems to be advisable: lateral position (change of position), resection and coagulation.

5.1 Lateroposition

In the case of an anatomically conditioned bony median position of the inferior turbinate, the indication for lateroposition (Figure 2) is given with slight mucosal swelling. With a compensatorily enlarged turbinate, a lateroposition can also be carried out simultaneously in septoplasty [23].

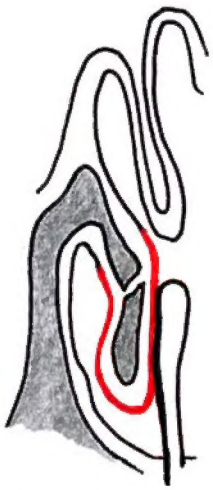

Figure 2: Lateroposition of the lower turbinate

The lateroposition has been described by Legler, amongst others, and is based on the recognition that the soft parts scar concentrically after subperiostal bone resection [50]. The crucial factor is that scarring does not affect the submucosa and the respiratory epithelium.
In his opinion it causes a permanent change in position and has proved to be more effective than fracturing alone. Following incision of the mucous membrane at the turbinate, the os turbinale is exposed, and a wedge-shaped bone resection at the base of the lateral nasal wall is carried out. If no satisfactory lateroposition results, then a predetermined breaking point on the whole of the os turbinale is helpful.
However, as the inferior turbinate has a resetting tendency towards the mid-line, therapeutic successes are

short-lived. Tolsdorff thus specified the lateral position in combination with other procedures for turbinate reduction, and achieved subjectively improved nasal breathing with 82.5% of patients (n=40) [51]. The length of the postoperative follow-up period was not presented. The lateroposition represents a technically simple and uncomplicated method. As postoperative intact mucosal conditions exist, bleeding and scabbing do not occur.

5.2 Resectioning procedures

5.2.1 Total turbinectomy

Total turbinectomy (Figure 3) is regarded as the most radical surgical measure on the inferior turbinate. Using scissors, the complete turbinate is detached directly at the base of the lateral nasal wall. The technique was used frequently in the first half of the 20th century, but was eventually discredited as there were severe long-term complications such as atrophic rhinitis and secondary ozaena. The result was the application of fewer destructive operations on the turbinate. In the 1970s and 1980s, total turbinectomy experienced a revival. The reason for this was the high success rate reported in studies to be between 63% and 94% [52], [53], [54].

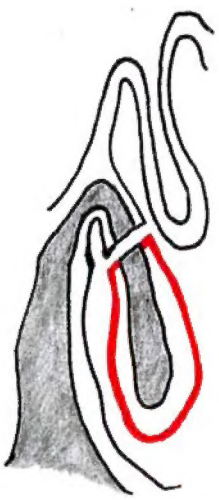

Figure 3: Total turbinectomy

In the recent literature, too, there are advocates of this method. In the studies referred to, long follow-up periods of up to 7 years and patient numbers between 38 and 357 made a positive impression. The success rates were given on average as 80%. The authors described total turbinectomy as a therapy with very few side effects, which even in a hot and dusty climate was accompanied by no complications in terms of atrophic rhinitis [55], [56], [57].

Nevertheless, negative results such as dryness of the nasal and pharyngeal mucosa as well as scarring with foetid secretion and secondary bleeding have repeatedly been observed. Moore and Kern have described in detail the problem of postoperative secondary atrophic rhinitis based on 242 cases, and point out the necessity of prospective, randomised studies with follow-up periods of between 5 and 10 years [58].

In view of the existing discussions in the literature, the high incongruity of the success rates is conspicuous. These vary between 0%, which are certainly doubtful, and the considerable figure of 89% [59]. With an incidence of between 3 and 9%, clinically relevant post-operative bleeding represents a further risk which should not be underestimated. Life-threatening bleeding requiring transfusion has also been reported [60], [61]. El-Silimy therefore recommends the use of a nasal dressing for 2 days [62], Courtiss even for a whole week [63].

An additional problem is the crust formation along the distinct wound surface which in the wound healing process encourages the formation of synechia. Oburra gives an average synechia rate of 15% [64].

Ravikumar et al. report on an unusual and severe complication following a bilateral turbinectomy. They observed a postoperative unilateral incomplete paresis of the nervus oculomotorius and the nervus trigeminus which only disappeared after 5 months. As a pathophysiological explanation, trauma-induced microembolisms or a vasospasm due to an adrenalin-containing local anaesthetic are discussed [65].

It is not surprising if the flow resistance is reduced through a complete resection of the inferior turbinate, and the success rates seem to be encouraging at first glance. Nevertheless, this method cannot be recommended as the underlying therapeutic concept is too mechanistic. The problem of obstruction of nasal breathing cannot be solved by a maximum cross-sectional enlargement of the nasal cavity without taking the turbinate into consideration as a functional organ for climatisation, humidification and cleaning [66].

Huizing and de Groot go one step further and even refer to a total turbinectomy as a "nasal crime". They therefore advise never to resect more than half the inferior turbinate [33].

5.2.2 Partial turbinectomy

With a partial turbinectomy (Figure 4), mucosal membrane and bones are resected in the front third of the turbinate. In the literature a variety of techniques are cited where the turbinate head is frequently found in the operative specimen. Spector carried out a resection with a diagonal incision in order to remove primarily the tissue of the anterior turbinate area and to preserve the head of the inferior turbinate. He reported good results over a long-term observation period of 15 years [67]. Faulcon's group treated 50 patients through a subtotal resection. The retrospective analysis after 2 years revealed a success rate of 80%; complications, in particular scabbing, were not observed [68].

This implies that no large wound surface and exposed bones were left. The comparison with other studies confirms that scabbing was not actually observed [69], [70]. However, the risk of secondary bleeding is given as 2% [71]. Davis and Nishioka were the first to carry out the

method of endoscopic partial turbinate resection using a shaver [72].

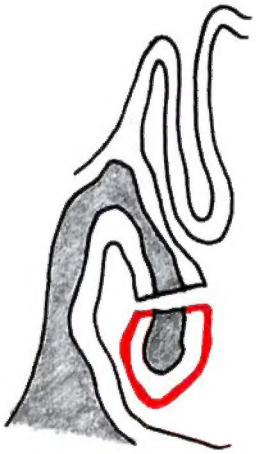

Figure 4: Subtotal turbinectomy

The shaver has been used for about 13 years especially for partial turbinectomy of the lateral mucosal section including the bone [73], [74]. Friedman and van Delden also use the shaver intraturbinally and suggest this variation as a technically safe alternative [70], [75]. After completion of the resection, the lateral mucosal plate is placed over the remaining bone and fixed with a fibrin-containing haemostypticum. The endoscopy has the advantage of better visualisation and offers the possibility of a specific caustic. The technique appears to be performed quickly and reliably as no postoperative bleeding occurs in so far as the soft parts medial of the os turbinale (mucosa, submucosa with sinusoids and periost) are preserved. A prospective, randomised study with long-term results, but with a small number of patients (n=19), has now been made. Joniau et al. have compared the partial turbinectomy with shaver to the submucosal caustic [43]. The follow-up period was 5 years, after this there was a persistent therapy success in the patient group which was treated with the shaver.

With this technique there is also incomplete information in the literature with regard to success rate. This is due on the one hand to the varying lengths of the follow-up periods, and on the other to the varying resection proportions. In Warwick-Brown and Marks' study it becomes clear that only long-term follow-ups of more than 4 years have real value with regard to therapy success [76]. In their retrospective study on 307 patients over 16 years of age, after one month 82% of postoperative patients were satisfied, after 3 months 60%, after 1 year 54% and after 4 to 16 years 41%. These findings are also confirmed by Passali et al. [77].

In summary this technique also appears too destructive according to the present state of research, as the turbinate head is not preserved, and its diffuser and regulator function then fails.

5.2.3 Submucosal turbinectomy

In 1951 the technique of submucosal turbinectomy (Figure 5) was revived by Howard House after it had been forgotten at the beginning of the 20th century, despite its attractiveness [78]. He described the submucosal removal of the anterior third of the os turbinale via a vertical incision of the mucosa of the turbinate head. As the mucosa and the submucosa remain intact, volume is reduced without negatively altering the function. In a randomised comparative study on 382 patients with a follow-up period of 4 years, Passali discovered that the submucosal resection in combination with a lateralisation of the inferior turbinate showed the best long-term results regarding free nasal breathing, a quicker recovery of mucociliary clearance, and of local IgA secretion. Based on these results, he noted that the conservative surgical techniques for turbinate reduction should be used in preference [77].

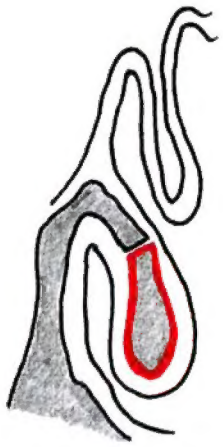

Figure 5: Submucosal turbinectomy

This statement is underlined when reference is made to the comparatively low risk of secondary bleeding of 2% and less crust formation [61].

Pollock and Rohlich also regard submucosal turbinectomy as a suitable method due to the good long-term results and the low complication rate [54].

Mori et al. found that the submucosal resection not only improves nasal breathing, but at the same time also positively influences symptoms of allergic rhinitis (rhinorrhea, itching nose) [79]. In a cohort study, follow-up examinations were carried out on 45 patients for 5 years. As well as significant improvements in nasal breathing, 50% of the allergic patients were postoperatively without antiallergic medication. The authors explain this by surgical sectioning of the nerve from the sphenopalatine foramen which transmits signals for triggering the allergic immune response.

5.2.4 Inferior (anterior) turbinoplasty

The term "inferior turbinoplasty" (Figure 6) goes back originally to Freer, who first described and published the technique in 1911 [80]. Numerous publications followed

which all "gave consideration" to the original technique with minimal modifications [81], [82], [83], [84], [85].

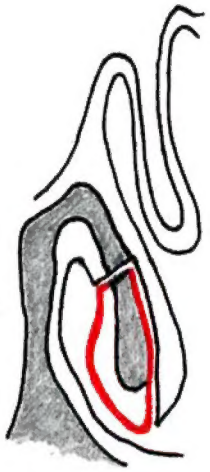

Figure 6: (Inferior) anterior turbinoplasty

With an inferior turbinoplasty, by means of an incision of 2–3 cm the anterocaudal projecting bone of the inferior turbinate is exposed and the mucoperiosteal flap is detached from the turbinate bone. Following this the turbinate head including bone is resected together with the lateral mucosal plate to a length of 2 cm. The remaining medial mucoperiosteal flap is laid laterally across the defect and secured with a tamponade. As the submucosal osseo-resection zone lies in the area of the turbinate head, in other words in an anterior position, the term anterior turbinoplasty is used.
The success rates are given as up to 93%, the incidence of secondary bleeding is between 1–20%. However, the observed studies only reach evidence level 1 as they have too few patients and a too short follow-up period [23], [86], [87], [88].
The inferior, anterior turbinoplasty represents a technique which preserves the mucosa and which enables a volume reduction in the flow-relevant area of the inferior turbinate. A posterior extension of the resection zone is feasible depending on the extent in each individual case.

5.2.5 Anterior turbinectomy

With this technique, the turbinate head, i.e. the os turbinale with covering mucosa, is completely resected along a length of 1.5–2 cm. For this purpose Fanous suggests a modified punch similar to a through-cutting Blaksley [89]. He treated 220 patients and gave a success rate of over 90% after a 4 year follow-up. Katz et al. report similarly good results [90]. The postoperative bleeding rate was 2.7%. However, further publications with greater number of subjects and long-term observations are missing.

5.2.6 Concho-antrumpexy

In 1967, Fateen suggested the lateralisation of the entire inferior turbinate in the direction of the maxillary sinus by means of an antrotomy [91]. First the turbinate has to be mobilised by fracturing. Median relocation was prevented by incorporating the rear turbinate end into the antrum under tension. A tamponade was left in for 24 hours. In 1992 Lannigan then modified the method, and was able to show rhinomanometrically that in 7 out of 12 patients, nasal airway resistance was reduced [92].
In a randomised study in the context of an intra-individual experimental design, Salam compared concho-antrumpexy with a total turbinectomy [93]. After 6 weeks and 6 months, 25 patients were interviewed regarding the subjective improvement of their nasal breathing. There was no significant difference between both surgical techniques. However, in 16% of patients dryness and crusting occurred on the side of the nose where the total turbinectomy had been carried out. On the contralateral side, the side of the concho-antrumpexy, there were no complications. Secondary bleeding and synechia did not occur. Contraindications for this procedure are young patients amidst their midfacial growth, a sinusitis maxillaris or a hyperplasia of the maxillary sinus.

5.3 Coagulating procedure

5.3.1 Submucosal diathermia

At the beginning of the 20th century, Neres started electrostatic coagulation; the next few decades saw the constant improvement of instruments [94]. If the submucosa of the inferior turbinate is treated with high-frequency deep heat (electromagnetic waves in the frequency range of 10^6–10^{10} Hz), a heat-induced wound results. The temperature produced by high frequency caustic can reach up to 800 °C, so that while the wound is healing, the venous sinusoids obliterate and scar over. The mucosa should as a rule be left untouched, which reduces the potential of swelling with hypertrophic mucosa [95].
A differentiation can be made between monopolar and bipolar caustic, where bipolar caustic is supposed to be easier to control. Williams reported on the loss of a turbinate due to necrosis following a monopolar caustic [96]. Technically the procedure is simple: the needle electrode is inserted submucosally into the turbinate body and advanced towards the turbinate end. Regarding the duration of the application of electricity, the opinions in the literature differ, between 3 and 6 seconds are reported [97], [98].
If the published results are considered, it can be seen that the short-term results (up to 2 months postoperative) are around 76%, whereby patients without allergic rhinitis profit most [71].
Farmer confirms this in his research and emphasises that therapeutic success is best with those patients who preoperatively already exhibited the least airway resistance [99]. He recommends that preoperative patient selection should be geared to this.
The long-term results are not encouraging, however, as the effects of turbinate reduction are not permanent. Lippert and Werner showed in a retrospective comparative

therapy study that after 2 postoperative years only 36% of patients were satisfied with the result [100].
On the topic of electro-surgery for turbinate reduction, Eccles' research group criticised a lack of standards in the area of instruments and methods used. It proposes that future advances in the area of clinical studies can only be made by defined standards [101].
Complications are rare, Warwick-Brown und Marks report on crusts on the puncture area in 43%, on bleeding in 10% and cacosmia in 12% of cases [76]. In an electron microscopical study, Wengraf discovered that the mucociliary transport behaviour is not influenced by this technique [102].
Submucosal diathermia today is still a popular therapeutic method as it is uncomplicated and simple to use.

5.3.2 Electrocoagulation of the turbinate mucosa

Only for the sake of completeness this procedure is mentioned as it knowingly damages the turbinate mucosa (Figure 7). The medial turbinate wall is contacted with cautery forceps in a posterior-anterior direction. The heat leads via coagulation of the tissue to necrosis and fibrosis and finally to shrinkage. On a mucosal and submucosal level, atrophic and metaplastic changes up to and including the loss of cilia can be found, which has a negative effect on the mucociliary transport. The main problem of the patient under treatment is distinct scabbing with formation of synechia. Therapeutic success is short-lived; the recurrence of turbinate hyperplasia cannot be prevented in the long-term [103].

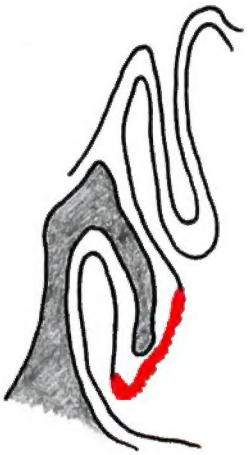

Figure 7: Electrocoagulation of the inferior turbinate

5.3.3 Cryotherapy

The cryotherapy method was originally introduced to oto-rhino-laryngology from the field of dermatology. The short-term contact of liquid nitrogen and cells at a temperature of −70 °C leads to a denaturation of cell proteins and to intracellular electrolyte displacement. As endothelial cells react in a similar way, microthromboses form in the vessels which cause a disturbance of perfusion with consecutive tissue ischaemia [104].
Ozenberger, one of the early advocates of this method, discovered that through the destruction of parasympathic nerves due to coldness, allergic-induced rhinitis in particular can be treated favourably ("... after freezing the nerve area ... relief of sneezing is almost immediate.") [105].
In the cited literature these interventions were carried out with local anaesthetics. There are no consistent recommendations on the contact times of the applicators on the mucosa. Kärja reports severe pain shortly after treatment; as well as slight bleeding, Ozenberger observed 2 septum perforations [106], [107].
The success rates vary, and due to a lack of consistent study protocols, it is unwise to discuss their significance. There is a consensus, however, that patients with vasomotoric rhinitis profit more from cryotherapy than patients with allergic rhinitis. This provides further evidence for the importance of an exact pretherapeutic selection of patients. Bumstead found a satisfaction rate of 92% in 50 patients after 2 years [108]. Chiossone gives a rate of 83% and Hartley puts his success rate at 50% [109], [110].
The short-term results appear to be satisfactory, but the therapeutic effect is on average significantly reduced after 1 year. Rakover and Rosen report a 35% rate of satisfaction with 50 follow-up patients [111]. The repetition of the operation is therefore recommended at relevant time intervals [112].
Compared to other methods for turbinate reduction, cryotherapy can no longer be recommended due to its poor long-term results and unpredictable resection zones [77].

5.3.4 Argon plasma coagulation

The method of contact-free treatment of tissue with monopolar high frequency caustic was introduced to surgery about 27 years ago. The haemostatic advantages of the "plasma scalpel" were exploited in particular in visceral surgery and thoracic surgery in order to stop bleeding from parenchymatous organs or to carry out blood-free resections.
With argon plasma coagulation the current flow is conducted through ionised argon gas (so-called plasma). Between an applicator and the tissue a hot arc of up to 3,000 °C forms which achieves the thermocoagulation effect. This occurs with no contact as the arc forms at a distance of about 2–10 mm between the tip of the applicator and the tissue. The penetration depth is 1–2 mm, so that a superficially homogenous desiccation zone is created so that the current flow is automatically interrupted. The resulting local necrosis zone caused during wound healing led to a cicatricial contraction of the surrounding issue [113].
In 2003, Bergler suggested numerous indications for the use of argon plasma coagulation in head and neck surgery [114]. As well as turbinate reduction, the effect described

can also be used in the removal of leukoplakia or of laryngeal papilloma. There are also positive experiences in the treatment of epistaxis in patients with hereditary telangiectasia.
Carrying out the operation under endoscopic control is recommended so that the posterior turbinate sections can be reached. In the meantime, the results of three larger studies on success rates, the histomorphoplogic changes and complications are available. In a prospective study on 121 patients and with a follow-up period of 16 months, Bergler et al. have determined that 76% of patients experienced improved nasal breathing after one week, and 83% after 12 months [115]. Furthermore they found histological indications for a re-epthelisation within 6 weeks. A ciliary function test after 3 months showed normal function. Ferri et al. were able to give a success rate of 87% on 157 patients they had observed for 24 months [116]. Gierek and Jura-Szoltys found an 88% success rate in a group of 70 treated patients after 3 months; this sank to 73% after 12 months in the case of the 47 patients who remained in the study group [117]. Ottaviani and his research group judged the procedure to have limited side effects; bleeding did not occur [118]. The operation can be carried out under a local anaesthetic and in outpatient facilities, nasal dressings are not required.
According to the outlined clinical studies, the importance of argon plasma coagulation cannot be finally assessed; further prospective and comparative studies should follow.

5.3.5 Radiofrequency therapy

For around 12 years, radiofrequency therapy has presented a further procedure for turbinate reduction. The principle of this method is the direct application of a high frequency current in the turbinate tissue. Although there is a temperature of on average no more than 75 °C this is nevertheless sufficient to induce thermonecrosis. The operation can be carried out under a local anaesthetic and in outpatient facilities. The probe is introduced into the turbinate head under direct vision. It should be ensured here that on the one hand the bone is not destroyed by direct thermal damage, and on the other hand that sufficient distance to the mucosa is maintained [119].
Smith provided the applicator needle with a thermo element which continuously measures the tissue temperature and which automatically ends the current supply through thermal feedback (the so-called somnoplasty procedure) [120].
Following recent literature, this method offers a good alternative for the treament of hypertrophic turbinates. Cavaliere has presented the advantages [121]. The need for nasal dressing for example, can be dispensed with, the mucociliary transport is not influenced, and crust formation is negligible. Thus demanding aftercare is not necessary.
Overall encouraging long-term results are reported. In 2004, Nease published the first prospective, randomised, blinded, placebo-controlled study [122]. Using a visual analogue scale, 32 patients were questioned on their subjective nasal breathing after 8 weeks and 6 months respectively. The verum group submitted significantly better values on the scale than the placebo group. Unfortunately no objective measurement systems for the evaluation of nasal respiratory resistance were used. Haster reports an 85% success rate after a control period of 39 months with 158 patients [123].
Fischer et al. achieved a therapeutic success rate of 91% with 22 patients after 3 months [119].
In a recently published meta-analysis, Hytönen and coworkers came to the conclusion that radio frequency therapy of the turbinate represents a safe, and for the patient less stressful, procedure [124].

5.3.6 Laser surgical procedures

In 1977, Lenz reduced an inferior turbinate with the help of an argon laser for the first time, and herby laid the foundation for the use of laser systems in turbinate surgery [125], [126] (Figure 8).

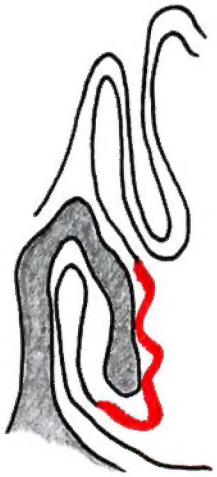

Figure 8: Laser surgery of the inferior turbinate

Lasers produce a beam of coherent light which is absorbed by tissue. The absorption is dependent upon the wavelength of the laser light. The energy released in this process leads to thermal damage of the tissue. The penetration depth is thus dependent upon the wavelength, the specific tissue absorption and the applied light energy. It is possible to apply the laser light either pulsed or continuously.
The indication for the use of the laser is the enlargement of the inferior turbinate, provided we are dealing with an isolated swelling of the mucosa. The laser is not suitable for the treatment of anatomical structural changes in the os turbinale. In a detailed survey dating from 2000, Lippert and Werner stress that an incorrect indication is the cause of the failures described in the literature. In their opinion, the ideal laser should provide the following advantages for turbinate reduction: 1. haemostatic characteristics, 2. precise tissue excision, 3. flexible application,

4. possibility for treatment of bone without any thermal damage of the surrounding area [8].
At the moment there are 6 different laser systems available, the carbon dioxide laser (CO_2), the argon laser, the neodymium: yttrium aluminium garnet laser (Nd:YAG), the copper titanium phosphate laser (CTP), the diode laser and the holmium: yttrium aluminium garnet laser (Ho:YAG).

CO_2 laser

The CO_2 laser, a gas laser, is the laser system most frequently used in head and neck surgery. The wavelength of the emitted light (9.60–10.60 µm) is mainly absorbed by water. As the penetration depth of the laser light is less than 1 mm, tissue ablation results. The methods used vary considerably. One possibility is the striped laser light application in a posterior anterior working direction [127].
Other authors describe an aggressive technique where the whole mucosa in the front third of the turbinate is vaporised [128], [129].
Englender has described the laser mucotomy where a superficial mucosa excision is carried out on the front half of the turbinate with the aid of a scanner system [130].
The laser can also be used as a cutting instrument for partial or total turbinectomy, or for intraturbinal resection [23].
Supported by their own research results, Lippert and Werner favour the single-spot method where single laser spots (laser power density 2,038 W/cm^2, application time: 1 second) hit the still swollen turbinate head in order to focally achieve mucosal shrinkage and scarring. The advantage of the method described is the rapid epithelisation of intact mucosal areas [131], [132].
Light and electron microscopic examinations of the laser-treated mucosa showed clearly that the ciliated epithelium regenerates to a certain degree, whereas the number of seromucinous glands and sinusoids in the submucosa were reduced permanently [133], [134]. All in all, the mucociliary transport time was significantly extended.
Fukutake was able to demonstrate that scarring takes up to one year and is even more pronounced, the more laser power is applied [129]. The single-spot method recommended by Lippert and Werner produces smaller, non-confluent wounds which heal after 3–6 weeks [131], [132].
The delayed wound healing process has to be regarded as a disadvantage. An extended phase of fibrin exsudation and crust formation results, which requires intensive after-care. A dosage reduction does protect the surrounding mucosa, but this means that as a rule the volume effect is less [135]. It seems worth mentioning that in the case of a deviation of the septum, a laser reduction of the inferior turbinate is associated with an increased risk of septal perforation [135].
The use of the CO_2 laser requires a higher rate of secondary bleeding compared to the diode laser and the Nd:YAG laser. DeRowe attributes this to the cutting character of the CO_2 laser [136]. A nasal dressing is recommended, at least for some hours. The use under local anaesthetic is advantageous.
The published long-term results reveal a considerable difference and range between 50% and 100%. Almost all studies are retrospective, not comparative and describe different laser surgery techniques [137], [138].
The results of these inhomogeneous studies are therefore doubtful. Lippert and Werner see this more optimistically and report long-term results of between 76% and 93%, independently of surgical techniques [8].
In 1998, DeRowe published a prospective study in which the results of a variety of laser systems were compared to each other [136]. A significant difference could not be established.
There seems to be no significant difference in regard to therapeutic success with allergic and non-allergic patients. Takeno et al. reviewed the effectiveness of the CO_2 laser on patients with seasonal and perennial allergies [139]. The 4 months follow-up revealed that patients with seasonal allergies profited from the operation; however, success seems only to be short-termed.

Argon laser

The argon laser is an ion laser with a wavelength of 0.48–0.52 µm. The absorption by haemoglobin makes it an ideal instrument for the treatment of pathological vascular alterations. The haemostatic effect is utilised in the well-vascularised front third of the inferior turbinate. Therapy of the intranasal "Osler spots" in the case of hereditary telangiectasia was described by Parkin and Dixon in 1981 [140].
Turbinate reduction as a treatment option has already been mentioned above. The argon laser is usually used in continuous mode with 2 to 4 watts. With the help of a quartz protective tube, the laser fibre is prevented from contamination [141].
Lenz carried out laser-line carbonisation at the free edge of the inferior turbinate under local anaesthesia. He recorded his 8 year experience with the argon laser in a publication in 1985 [142]. At this time 2,000 patients were treated, presenting follow up data on 411 patients over a period of 5 years. 80% of patients were satisfied with the results of the therapy. All operations were carried out under local anaesthesia; a nasal dressing was not necessary. Lenz noted extended wound healing, which can take between 3 and 6 weeks, as a disadvantage. Due to crust formation, intensive follow-up care is recommended as a synechia prophylaxis.
As the acquisition costs compared to the other laser systems are considerably higher, the argon laser has not been able to establish itself on a wide level.

Neodymium: yttrium aluminium garnet laser (Nd:YAG-laser)

The Nd:YAG laser is a so-called solid-state laser with a wave length in the infrared range of 1.06 µm. Its penetration depth is given as up to 1 cm [143].
As the thermal reaction is higher than in the other laser systems, limiting energy to 1,000 watt/cm^2 is recommended. In order to prevent osteitis of the os turbinale, the length of application should be limited to a maximum of 0.5 seconds [144].
In the case of the Nd:YAG laser, the laser light application is carried out using a flexible light fibre under endoscopic control. Contact or non-contact modes may be applied. Due to the high amount of released energy that is absorbed into the submucosal venous plexus, a vasculitis is induced which markedly reduces the volume of the turbinate while the wound is healing. However, the unwanted changes to the mucosa are considerable. Lippert and Werner report on crust formation with increased danger of synechia formation [131]. With dosed usage of the laser the respiratory ciliated epithelium remains largely intact and does not significantly impair mucociliary clearance. In direct contrast to the CO_2 laser, the wound healing process takes place far more slowly and demands that the patient is prepared to wait for several months until the therapeutic goal is reached. Serious intraoperative and postoperative bleeding did not occur. They see the enlargement of the whole of the inferior turbinate as the primary indication for the use of the Nd:YAG lasers.
As well as the single-spot method, numerous other incision and resection variations have been described. Interstitial application is also possible [8].
Vagnetti and coworkers resected a mucosal wedge along the whole length of the turbinate [145]. With 121 patients and a follow-up period of 1 year, a success rate of 85.9% was reported.
Olthoff used the Nd:YAG laser in contact mode for volume reduction treatment with a total of 83 patients with allergic and vasomotor rhinopathy [146]. After 4 weeks he found a success rate of 80% in both groups.
If we look at these results we can see that they are comparable to those of conventional surgical procedures. The recovery phase, which can take up several months, is a serious drawback to this method, and seems no longer appropriate today.

Copper-titanium-phosphate-laser (CTP laser)

The CTP laser belongs to the group of solid-state lasers. It produces laser light within a visible spectrum, a green light. The wavelength is 532 nm and is thus absorbed very well by haemoglobin and melanin. Through the affinity to haemoglobin, a selective coagulation of the surface mucosal vessels is possible up to a depth of 0.5 mm. The light energy is absorbed by the haemoglobin, which denaturates the protein and damage the endothelium; microvessel closure results [147].
For endonasal application, an endoscope with an integrated light-guide channel was developed.
In 1989 Levine reported the use of a CTP laser for the treatment of a turbinate dysfunction for the first time [148]. In contact mode, the front turbinate segments were carbonised in a cross-shape way in order to preserve small epithelial islands. After about 6 to 8 weeks the healing process was completed, the success rate was 85%.
More recent studies also underline these high rates of success between 81% and 87% [149], [150]. One disadvantage that should be mentioned is the postoperative obstruction of the nose by mucosal oedema and fibrin exudation which lasts for weeks. Severe bleeding did not occur. On evaluation of these studies, an inhomogeneity concerning case numbers, the follow-up period and the laser position is again apparent. The only constant parameter was the continuous wave mode. Overall the studies show that the CTP laser is suitable for the reduction of turbinates; it is safe to use and is uncomplicated. The reason for the limited distribution of the laser is the high cost coupled with the limited application.

Diode laser

The diode laser (Figure 9) produces invisible infrared light (810/940 nm wave length) and can cause thermal reactions in human mucosa to a depth of 5 mm. A useful characteristic is the high modulation range of the electrical current. The handy diode laser can be operated with little effort.
Initial experience was gained by Min's research group in 1996 [151]. Janda [152] and Caffier [153] were able to confirm the good results with the treatment of hypertrophic turbinates. Janda examined 76 patients after 6 and 12 months and discovered that after 6 months, 86% had improved nasal breathing, and after 12 months 76%.
In the case of 42 patients, Caffier was able to achieve a success rate of 88% after 6 months and a success rate of 74% after 12 months. He also discovered that after one week, no mucosal oedemas were detectable, and that after 6 weeks postoperatively there were no longer any crusts.
These encouraging results contradict DeRowe, who in his prospective comparative study achieved a success rate of 41% [136].
In comparison to other laser systems, the diode laser is less expensive to acquire.

Holmium-yttrium-aluminium-granat-laser (Ho:YAG-laser)

The solid-state holmium:YAG laser (Ho:YAG Laser) has a wave length of 2,123 nm. It is characterised by a very small penetration depth of 0.4 mm, as well as the ability to cut bone with precision. The laser effect is based upon photoablation so that practically no perifocal tissue damage results. Its good ablation properties are the reason that only a very little thermal energy is effective on the surface of the mucosa. Despite this, fibrin exuda-

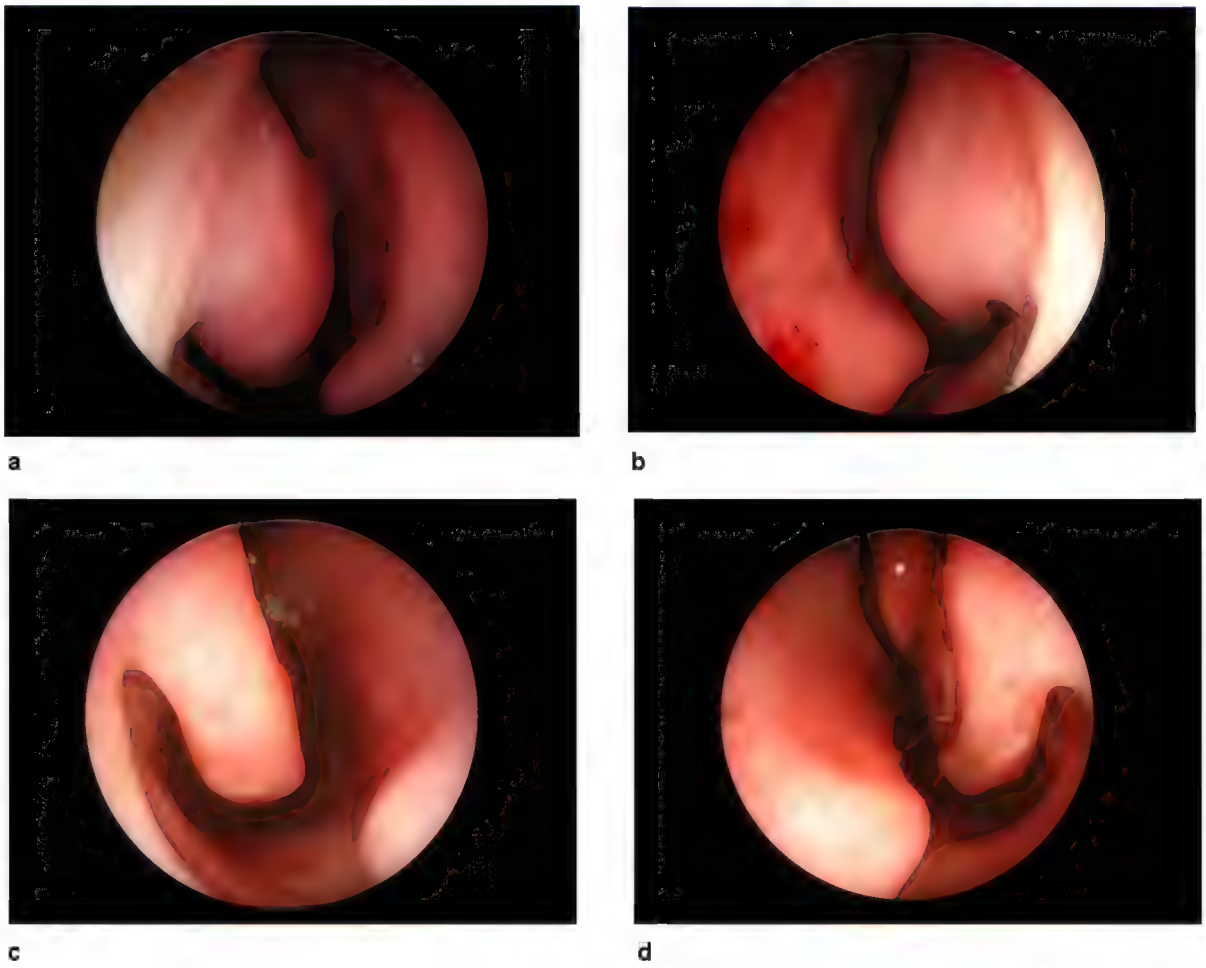

Figure 9a–d: Treatment of both hypertrophic inferior turbinates with the diode laser (Biolitec AG, Jena, Germany). Laser settings: 10 watt, continuous wave, laser fibre: 400 µm, treatment energy: 279.16 joules, treatment time: 28.05 secs.
a: right inferior turbinate preoperative; b: left inferior turbinate preoperative; c: right inferior turbinate at 6 weeks postoperative; d: left inferior turbinate at 6 weeks postoperative (Pictures courtesy Prof. Lindemann/ENT-Dept. Ulm University).

tion and crust formation occur. These have healed within 3 to 6 weeks. In comparison to the other laser systems referred to, slight bleeding may occur postoperatively as effective coagulation is not possible [154].

Clinical experience with the Ho:YAG laser is low, measured against previously published studies. This is primarily due to the limited distribution of the costly system.

Serrano et al. report a success rate of 52% [155], Leunig was able to achieve improved nasal breathing with 77% of 52 patients after one year [156]. In a comparative analysis between the Ho:YAG laser and the diode laser, Sroka and Leunig were able to determine different success rates after a 3 year follow-up period: 67.5% for the Ho:YAG laser, and 74.4% for the diodelaser [157]. Rejali compared the Ho:YAG laser with submucosal and superficial diathermy in the turbinates of children [158]. The success rate for the laser was 50% and 36% for the high-frequency caustic. Moreover, the poor long-term effect stood out negatively.

The question remains whether the laser fits into the overall concept of modern, functional rhinosurgery: individual volume reduction in combination with maintaining turbinate functionality. The technical problem which is not yet solved satisfactorily is the energy dosage. Large amounts of energy do mean good reduction in volume, but also at the same time extensive damage to the mucosa and submucosa. The best possible preservation of the epithelium through low amounts of energy in some cases means an inadequate reduction in volume. Sapci drew attention to this problem in a prospective, randomised control study on 45 patients [159]. He compared the efficiency of 3 techniques: CO_2 laser ablation, partial turbinectomy and radiofrequency ablation. All examined methods for turbinate reduction were suitable for the significant reduction of nasal respiratory resistance. In the context of functional assessment, it was revealed that mucosal damage caused by the CO_2 laser was more extensive than that experienced with the other two methods. The transport time for serum albumin marked with Tc-99m as an indicator of mucociliary clearance was significantly increased 3 months postoperatively.

The laser systems referred to only partially fulfil the conditions in question at present, so that technological advancement has to be hoped for. In the future, computer-aided lasers will make optimal use of the biophysical effects of the individual systems, so that a defined tissue excision with better protection of the adjacent structures will be possible [160].

6 Treatment of the middle turbinate

The functional tasks of the middle turbinate comprise the heating and humidifying of the inhaled air; in addition they direct air flow towards the olfactorily significant areas at the frontal base. At the same time they prevent a turbulent flow in the middle nasal meatus, and thus indirectly support mucociliary clearance. In contrast to the inferior turbinate, nasal respiratory resistance is not regulated by the middle turbinate [161].

The pathological changes in the middle turbinate are summarised in 4.2. The indications for postoperative correction of the turbinate body or of medialisation can be implied from this.

The surgical aim of interventions on the middle turbinate should be a turbinate anatomically adapted to individual patient needs, remaining functionally intact [104], [162], [163]. There are numerous publications on the treatment of the middle turbinate in the context of operations of the paranasal sinuses [164], [165], [166], [167], [168]. Measures suggested include, for example, double-sided caustic, cryotherapy, laser surgical procedures, partial or total resection.

In order to systematise the different kinds of surgical approaches, a division into 3 groups seems useful: medialisation (altering the position), reduction and resection.

6.1 Temporary medialisation by septum-turbinate-suture

The lateralisation of the middle turbinate is a negative result of functional endoscopic paranasal interventions. The risk is currently around 43% [169].

A medialisation does not guarantee a lack of recurrence; however, Friedman et al. were able to demonstrate clearly that in 94% of cases with medialisation, patients remain asymptomatic [170]. A change of position of the middle turbinate was dispensed with; only 60% of patients were free of symptoms.

The therapeutic aim of this technique consists of the medialisation of the middle turbinate until the wound healing process in the middle nasal meatus is completed. In the Rettinger technique, the middle turbinate is attached by deep stitching to the septum using an absorbable vicryl 3/0 mattress suture. The return stitch is made so that the suture lies in front of the head of the turbinate. The thread is cut off short in order to minimise crust formation. In a retrospective study, 85% of middle turbinates were in a medial position with no contact to the lateral nasal wall and the septum. In 15% there were selective adhesions either laterally or medially, but with no adverse results for either sense of smell or nasal breathing. The advantage is a controlled approximation of the turbinate to the septum without the necessity of a tamponade of the middle nasal meatus [171].

Hewitt und Orlandi were able to confirm these results in a retrospective study [172]. In 89.2% of 85 patients, they found a medial position of the middle turbinate, and in 10.8% adhesions.

In 99% of 31 patients, Thornton found a medially positioned middle turbinate [173].

Koch was also able to confirm the overall positive results of the septum turbinate suture [174]. He examined 55 patients 9 to 18 months postoperatively and found a small lateral synechia in only one patient. Some patients did report hyposmia, but this was spontaneously reversible after the stitches were removed and the turbinate relocated.

A suture-free technique for the permanent medialisation was presented by Friedman and Schalch in 2008 [175]. They use a shaver to produce corresponding wound surfaces and then adhere the middle turbinate to the septum with a bovine albumin tissue adhesive (Bio-Glue. Cryolife, Inc., Kennesaw, GA, USA). The adhesive reaches full holding power after only 2 minutes. This means that there is no need for a tamponade. 212 patients were operated on using this method and monitored for 6 months. In 93% of cases medially positioned turbinates were found. Serious complications did not occur, and in particular there was no olfactory dysfunction [176].

Bolger et al. applied a different philosophy by producing a controlled synechia between the medial blade of the middle turbinate and the septal mucosa [177]. For this reason, opposed incisions in the mucosa are made and the turbinate medially displaced by tamponade of the middle nasal meatus. The tamponade remains in situ for approximately 10 days. According to their statements, the suture technique appears too traumatising. Success rates are not mentioned in the study.

The surveys quoted show convincing results. Complications resulting from septal-turbinate-suture itself are not reported.

6.2 Narrowing of the middle turbinate

The concha bullosa can be individually pneumatised (see point 4.2). The degree of pneumatisation correlates with the complaints. Whilst the pneumatisation variants 1 and 2 tend to remain asymptomatic, in the case of type 3 (enlarged concha bullosa), symptoms of chronic sinusitis or dull mid-face pain are manifested. In these cases surgical treatment of the concha bullosa, in the sense of a reduction, for example, is indicated. Numerous surgical techniques, which do not really differ as far as the method is concerned, are listed in the literature. Pirsig [178] and Huizing [179] describe, for example, a narrowing of the middle turbinate where they first remove the mucosa from both sides, and then open the concha and resect the inner mucosa lining together with the middle bony lamella.

In 1996, Har-el and Slavit suggested a slight modification [180]. Out of 43 patients, three developed a synechia postoperatively between middle turbinate and lateral wall. The authors recommend the curettage of the inner mucosa for the prophylaxis of mucoceles, a rare complication when reducing the size of the concha bullosa.

Har-el und Slavit's technique was modified by Dogru in 2001 [181]. Following a vertical mucosal incision above the turbinate head, the concha is entered and the mucosa completely removed. Finally, the concha bullosa is reduced from superior to inferior and then to posterior using an especially non-traumatic Blakesly. This method (n=31) was compared with the lateral turbinoplasty (n=100). The follow-up period was between 4 and 47 months. In group I (reduction) synechia were found in 9.7%, in group II (partial lateral turbinoplasty) in 27%. The difference was significant.

A more radical procedure for reduction of the concha bullosa is the lateral partial turbinectomy, a procedure which has already been described by Messerklinger. Here, a wound surface is created which forms the foundation for lateral synechia. This wound surface can be covered by a posteriorally pedicalled mucosal flap. Sigston and Iseli suggested this method in 2004 [182]. In their retrospective, comparative study, the mucosal flap was used in 28 patients (group I), compared to 19 patients of the control group (group II). After 3 months there was a 7% incidence of synechia in group I, group II showed a synechia rate of 21%.

If the middle turbinate is either anatomically or pathologically enlarged, and symptoms result, the reduction using the technique cited would be a therapy option. Here methods which preserve the lateral and medial mucosa would seem to be best suitable from the functional standpoint of wound biology.

6.3 Resection of the middle turbinate

The question whether the middle turbinate should be preserved or resected in paranasal sinus surgery has a long history dating back to 1920. Since then it has been the subject of vehement controversy. The advocates routinely resect the middle turbinate in order to prevent the occurrence of synechia and to keep the maxillary sinus ostium free [183], [184], [185], [186].

With very few exceptions, the advocates of the Messerklinger school of thought respect the middle turbinate as an important functional organ and as an anatomical landmark [187], [188]. The evaluation of other texts also showed no clear trend so far. Swanson et al. report an increased risk of frontal sinusitis after partial resection of the middle turbinate [189]. However, the increased mucosal swelling in the frontal sinus was regarded as pathological.

Other authors found no increased incidence of frontal sinusitis after turbinate resection, but rather observed an increased patency rate of the middle nasal passage. In their study of 155 patients who had received a partial turbinate reduction, Fortune and Duncavage report a sinusitis rate of 10% [190]. Havas and Lowinger were able to confirm this figure [191].

Giacchi et al. carried out 100 ethmoidectomy procedures, in 50 patients the middle turbinate was removed, whereas in the remaining 50 patients the turbinate was preserved [192].

The follow-up period was 2 years. No differences were found between both groups with regard to an increased incidence of frontal sinusitis or a stenosis of the frontal recess.

All studies quoted were retrospective and are therefore limited in their significance. A prospective, intra-individual study of 31 patients with a 2 year follow-up period was presented by Shih and his research group [193]. He resected only the right middle turbinate, the left remained intact. 8/31 patients developed postoperative adhesions, 4 on the right-hand side, and 3 on the left, 1 bilaterally. The results were interpreted by the authors regarding that turbinate resection has no negative effect on the success of the therapy in case of functional endoscopic paranasal sinus interventions.

As there is still a lack of randomised, controlled studies with long-term results regarding the success rate of partial turbinate resection, it is difficult to make a clear recommendation. It seems apparent that partial turbinate resection is accompanied by a lower adhesion rate than with the total removal of the middle turbinate [194].

Experts agree in general that a middle turbinate with polyp-like changes, where the mucosa is extensively damaged or is strongly enlarged in terms of a concha bullosa, should be partially resected [195], [196].

7 Turbinate surgery during childhood

The anatomical dimensions of a child's nose are tiny: the length of the inferior turbinate in a three-year old is about 30 mm, an adult's is around 35 to 50 mm. The distance to the nasal floor in a one-year old is about 4 mm, in an adult 6.8 mm [10].

The cause of obstructed nasal breathing in children in this already very limited discussion, after excluding septal deviation, adenoids and foreign bodies, might be hypertrophy of the turbinate. This is often observed in the case of allergic rhinitis. Especially among children with asthma, bronchial and simultaneous cortisone resistance, pathologically enlarged turbinates can be found regularly [197].

A rhinitis medicamentosa should be considered differential diagnostically with the newly born and infants who have been given decongestant nose drops. The mucosa of the turbinate reacts paradoxically and leads via an oedema to an obstruction of nasal breathing, the exact pathomechanism is unclear [198].

A secondary hypertrophy of the turbinate of unclear aetiology is the "stuffy nose syndrome". Here, a nasal obstruction occurs which can last for days or even weeks, and which responds well to decongestant drugs [199].

Less common causes are deformities in the context of genetic alterations or dental deformities [200], [201]. The clinical symptoms include snoring at night, breathing with open mouth, rhinorrhea, xerostomia or anosmia.

The effects of obstructed nasal breathing are a disturbed conditioning of respiratory air with recidivous infections

of upper respiratory tracts and possibly impairment of facial growth with permanent mouth breathing [202].
According to Stoll, the surgical therapy of turbinates in childhood should be carried out as defensively and as conservatively as possible in order to avoid growth disorders resulting from surgery. For this reason, gentle methods for reduction of the turbinate mucosa which may be repeated are recommended. Given the lack of scientific groundwork, Stoll regards extended resection as unacceptable [203].
Thompson, on the other hand, carried out partial or total turbinectomies on 22 children aged between 9 and 15 [204]. In a follow-up period of 7 to 51 months, he achieved a success rate of 68%. The criterion was a questionnaire filled out by children and their parents. Complications such as bleeding, synechia or olfactory dysfunction did not occur.
Ophir et al. treated 17 patients under 16 years old with a total turbinectomy [53]. He reported a success rate of 91% and stressed that he had seen no child with either crust formation, atrophic rhinitis or ozaena.
Percodani et al. report similarly good results of 90% with 38 children who had also been treated with a total turbinectomy [205]. With 27.3% of the children, the asthmatic symptoms improved. The follow-up period was between 6 months and four years.
In a recent study from 2003, Segal et al. report their results after carrying out total turbinectomies on 227 children, all less than 10 years of age [206]. After one year, 78.9% were free of symptoms, with 14.5% the symptoms improved, 6.6% showed no change. In no instance there was a postoperative deterioration of the nasal obstruction. However, 6.6% of the children developed synechia in the course of wound healing which often demand an operative intervention. According to the authors' information, mid-facial growth was by and large normal over a follow-up period of 14 years. In the case of one child a CT examination revealed a hypoplastic maxillary sinus. Clinical indications for a rhinitis atrophicans or an ozaena after 14 years were not demonstrated. Segal et al. indicated that the most frequent reason for therapeutic failure was an incomplete turbinate resection. In their opinion, the complication rate after a total turbinate resection is lower than expected, which is benefited in part by the warm, moist climate in Israel.
The presented study is convincing due to the high number of cohorts and the length of the follow-up period. Nevertheless, the study has to be viewed with reservations: due to the young age of the patients, nasal respiratory air was evaluated with Podoshin-Gertner plates [207]. Here the amount of expiratory air is calculated by the size of the condensation surface on a metal plate. Furthermore, an atrophic rhinitis can only manifest itself in adulthood, as Moore and Kern have observed [58].
Weidner and Sulzner carried out an inferior turbinectomy in 64 children and achieved a success rate of 89% after 24 months [208]. The striped mucosal resection is a less aggressive technique as only the visible excess mucosa is tangentially excised with scissors. Medial portions of mucosa are preserved for the prophylaxis of synechia. It could be demonstrated that the mucosa regenerates and grows again [209].
For this reason, long-term therapy success cannot be expected. According to Stoll, it is sufficient if an improvement in nasal breathing in a particular phase of growth is achieved.
There is an indication for submucosal turbinoplasty if in addition to a thickening of the mucosa, there is also a spongious prominence of the os turbinale. As anterior turbinoplasty also represents a method for the preservation of mucosa, it can be recommended for use with children without having to anticipate any negative delayed effects [203].
The rhinological indications for the application of various laser systems in childhood are similar to those in adulthood. As well as the CO_2 laser, the argon laser can be used for turbinate reduction in children. As the Nd:YAG laser has a deeper penetration depth, it should not be used with children [210].
The application of the CO_2 laser causes only minimal pain postoperatively; the risk of nasal bleeding is minimised. For this reason there is as a rule no need for a nasal dressing, which is particularly uncomfortable for children [211].
Rejali's research group was able to gain new experience with the Ho:YAG laser in the context of turbinate reduction [212]. According to them, the Ho:YAG laser is suitable for the removal of thickened mucosa with few complications. One disadvantage is the short-term therapeutic effect as a result of the limited excision of tissue.
In compliance with certain treatment parameters, the CO_2 laser can be used as minimal invasive surgery with the single-spot technique with children under general anaesthetic. Parents should be informed about the intensive aftercare with nasal rinses and ointments [213].

8 "Empty" nose syndrome

The descriptive term "empty nose syndrome" (ENS), or more exactly "empty nose syndrome of Stenkvist", was originally coined in 1994 by Kern and Stenkvist who, when investigating coronary CT images of paranasal sinuses, recognised a considerable loss of tissue in the region of the inferior and middle turbinates, and who described this condition as "empty nose" (Figure 10).
Kern and Stenkvist made the clinical observation that those patients who had their inferior and the middle turbinate either partially or totally resected increasingly suffered from the symptoms of an obstruction of nasal breathing and endonasal crusting and dryness. Although the intranasal air space was expanded by the resection of the turbinate, a contrary effect occurred, the so-called "paradoxical nasal obstruction". In Anglo-American usage, ENS is divided up into three subtypes: the ENS inferior turbinate (ENS-IT) refers to the situation when the inferior turbinate has been removed. ENS middle turbinate (ENS-MT) describes the condition after removal of the middle

turbinate, and ENS-both refers to the resection of all turbinates [58].

Figure 10: Coronary computer tomography representation of a patient with ENS. Both the inferior and middle turbinates have been resected, only vestiges of the turbinate have been preserved.

The ENS was therefore defined as an iatrogenically caused condition which is also referred to as secondary atrophic rhinitis, and which is thus to be distinguished from primary atrophic rhinitis. Further causes of secondary atrophic rhinitis are chronic rhinosinusitis, granulomatous diseases, nasal trauma or radiation therapy [214], [215].

The onset of primary atrophic rhinitis is often spontaneous without any recognisable cause, and is typified by a slowly progressing course. Histologically, it is characterised by the lack of goblet cells and cilia, as well as the presence of inflammatory infiltrates.

An endarteritis obliterans with thickening of the vessels and dilated subepithelial capillaries cause impaired mucosa regeneration and a greater vulnerability of the epithelium. The histological changes explain the impaired mucociliary transport. The moisture in the nose is reduced as the mucinous cells are missing and nasal secretion reduces. The fluid sol layer on the cell surface and the more viscous gel layer decrease, the cilia, which are normally surrounded by this fluid medium, stop functioning. Stasis of nasal secretion follows with the formation of bacterially superinfected crusts. All in all, this situation of impaired local defences against infections contributes to rhinitis and sinusitis [216], [217].

The aetiology of primary atrophic rhinitis is unclear; numerous hypotheses describing its development are under discussion: endocrine factors, nutritional deficits, as well as bacterial infections with Klebsiella ozaena, Bacillus foetidus, Staphylococcus aureus, Proteus mirabilis and Escherichia coli. The prevalence of these diseases is unknown; it is only known that primary atrophic rhinitis in developing countries is more frequent than in highly developed industrial nations. This may be due to a poor nutritional situation on the one hand, and on insufficient supply of antibiotics on the other. Primary atrophic rhinitis is closely connected to recurrent sinusitis, epistaxis, anosmia, septal perforation and midfacial pain. It is characterised by progressive mucosal atrophy in the course of which dryness, crust formation and nasal foetor occur. These symptoms can also be found with patients who suffer from ENS [218]. The leading symptom with ENS patients is, however, the paradoxical nasal obstruction which frequently accompanied by shortness of breath and undifferentiated breathing difficulties [219], [220].

In the literature, terminology varies inconsistently between atrophic rhinitis, rhinitis sicca and ozaena. Rhinitis sicca describes chronically dry nasal mucosa with hypertrophy [221]. Ozaena is also a chronic disorder of the nasal mucosa, characterised by a progressive atrophy of the mucosa in connection with bone resorption both at the os turbinale (= concha nasalis inferior), as well as at the bony suspension of the middle turbinate at the frontal base (= concha nasalis media). In this way ozaena differs from atrophic rhinitis, which only seldom affects submucosal tissue. Rhinoscopically, an enlargement of the cross section of the main nasal cavity can be seen, particularly in the posterior sections and in the inferior and middle nasal passage. Similarly to enlargement of the endonasal space, crust formation takes place in the middle and posterior areas of the nose. One of the main symptoms of ozaena is foetid nasal odour which can be so overpowering that social isolation becomes a threat. As patients with ozaena suffer from a secondary anosmia, they are not themselves aware of the foetor. The incidence of ozaena in industrial nations has significantly diminished in recent years thanks to the increased use of antibiotics.

The main functions of the human nose are warming, humidification and cleaning of inspiratory air. The healthy nose adapts the inhaled air within seconds to the requirements necessary for an optimal pulmonary gas exchange [222].

In order to carry out this task, both the anatomical and the morphological conditions must function equivalently. The geometry of the interior of the nose with special respect to the lateral nasal wall (beginning of the inferior turbinate) and the frontal base (beginning of the middle turbinate), as well as the functioning mucosa, contribute primarily to this. It is considered common knowledge today that for the effectiveness of air-conditioning in the nose, the following factors are of particular relevance:

- the functional mucosal surface,
- the relationship between the mucosal surface and the nasal volume,
- the contact time of respiratory air with the mucosa,
- the flow characteristics of air,
- the temperature and humidity change between nasal wall and streaming air.

The turbinates, in particular the inferior turbinates, act as diffusers of the air flow which changes from a laminar

to turbulent flow after hitting the turbinate head. It is well-known that this flow effect is of great importance for the warming and hydration of air at the interface to the mucosa. A good air passage is synonymous with lower nasal airway resistance. If the airway resistance is increased, either through anatomically determined changes in the nose, or through unphysiological flow behaviour of inhaled air, then oral respiration immediately begins. In this case the nose can no longer fulfil its respiratory function [223]. Functional disturbances therefore have direct negative effects on air-conditioning. Causes for the breakdown of this sensitive system might be numerous anatomo-pathological changes in the nasal inlets (vestibular stenosis, a broad columella and columella retraction with nasal tip ptosis, etc.), in the nasal septum (septal deviation, nasal valve stenosis, perforation of the septum) and/or in the lateral nasal wall (turbinate hypertrophy, the absence of one or all turbinates, external deformations of the nose). These can occur either individually or combined.

ENS, a special form of secondary atrophic rhinitis, frequently occurs after resection of individual or all turbinates, and is considered as a prime example of the variability of symptoms from which those affected suffer. Emphasis is placed upon subjectively impeded nasal breathing which at first seems illogical as the internal nose in cross-section is wide. A "paradoxical nasal obstruction" is referred to. For ENT specialists, the chronically ill patients are difficult to treat as the therapeutic possibilities are limited, and the patients' compliance is thus not sufficient. As ENS presents a surgically irreversible situation, the patient is often recommended conservative therapy. This is largely limited to care of the mucosa through daily inhalations and ointment instillations. In the case of strong crust formation, with or without ozaena, a long-term antibiotic therapy may be indicated. Nevertheless, even with good effectiveness of the therapeutic measures just mentioned, only alleviation, but no permanent solution to the problem, can be achieved [219].

Exact demographic figures for the prevalence in Germany are not available as the clinical profile on the part of the symptomatology is inhomogeneous and probably the exact diagnosis very frequently cannot be ascertained, despite the classic anamnesis of previous endonasal surgery. The causal link between pathological air flow and air-conditioning with ENS is described below.

In the context of a clinical study at the ENT University Clinic Ulm, the air-conditioning function of the nose was examined in vivo for the first time in a group of 10 ENS patients, and the flow dynamics of air during inspiration and expiration were presented through MRI-based numerical flow simulations. At the present time, there are no similar studies with the same high case numbers which are involved in this research.

The results presented in this study show that in comparison to the healthy control group, the temperature of inhaled air at the measuring points of the nasal valve and middle turbinate was significantly higher. The temperature at the nostrils in the ENS group was discretely lowered. The absolute humidity at all measuring points was lower in the ENS group than in the control group, significantly so in the nostril region. The dry nose sensation with ENS patients is explained by lowered humidity values of respiratory air. Increased crust formation can also be explained by the impaired conditioning function.

If we consider the speed of flow in relation to air temperature, we can see that in regions of high air temperatures, lower speed of flow occur at the same time. On the other hand, low air temperatures are accompanied by high speeds of flow. This observation explains why in the case of ENS patients the temperature was lower at the nostrils than in the rear sections of the nose. Lindemann's research group drew the same conclusions [224].

The phenomenon of "paradoxical nasal obstruction" with ENS has multifactorial causes. This means that several pathophysiological changes in the affected nose occur at the same time which negatively affect each there in their effectiveness and which interact with each other unfavourably for the respiratory function of the nose. These changes affect:

- the lowered nasal airway resistance,
- the unphysiological flow,
- the lack of functioning mucosal areas with simultaneous volume enlargement of the main nasal cavity,
- the temporarily reduced contact between air and mucosa.

Nasal breathing is responsible for around 50% to 80% of all airway-resistance [225].

This resistance results from the friction between streaming air and mucosa. Through the expansion of the nasal cross-section, respiratory resistance is reduced and thus the pressure gradient at the interface of air and mucosa. This causes a malfunction of the naso-pulmonary bronchomotor reflex, which can then cause a deterioration of pulmonary function. In contrast to this, the optimum nasal respiratory resistance is responsible for a dilatation of the peripheral bronchioles and an improved alveolar gas exchange. The existence of a naso-pulmonary reflex was first suspected in asthmatics and patients suffering from rhinitis [226].

It is well-known that mechanoreceptors, proprioceptors, thermoreceptors and nerve endings occur in the nasal mucosa, the number of which is largest in the region of the inferior and middle turbinate. Above all the activation of the temperature receptors through the inspiration of cold air would appear to be a main stimulus for the activation of the naso-pulmonary reflex. The nose thus protects as "first line of defence" the deeper respiratory tracts by inducing a bronchoconstriction [227].

At the same time, a further neurophysiological connection between the lungs and nose is suspected. In this case a reflex control of nasal blood vessels through pulmonary stretch receptors was shown in animal studies [225]. The possible reflex arc runs afferentially via the pulmonary stretch receptors in the vagal nerve towards the central nervous system, and makes contact with the blood ves-

sels in the nasal mucosa via efferent nerves in the vidian nerve.

Wrobel reports that the plate epithelial lining of the nostrils has the highest sensitivity to air flow so that the whole respiratory system can be adjusted early to changes in air flow [228]. After removal of the turbinate tissue, the number of receptors is reduced so it is probable that reduced tactile perception disrupts signals to the brain [229].

Despite the significantly enlarged volume of the main nasal cavity, the ENS patient cannot achieve any higher overall inspiratory flow. This has been proved in the study by the measurement results of the active anterior rhinomanometry and the acoustic rhinometry. The relationship between the volume of the nasal cavity and the mucosal surface is thus in a functional imbalance. Lindemann et al. have calculated that, after unilateral resection of the turbinate during tumour surgery on the paranasal sinuses, the ratio of the volume of the nasal cavity to the mucosal surface was 0.8 on the operated, and 0.3 on the non-operated side [224]. The volume enlargement brings about a simultaneous change in air flow which results in a disturbance in air-conditioning.

In this study, discretely higher temperature values in the ENS nose were measured, the absolute humidity in the whole nose was reduced, however. The nasal mucosa in the case of ENS is thus warmer and dryer, making it safe to assume that on the one hand the nasopulmonary reflex mechanism and the introduction of free nasal breathing are affected at the same time. The symptom of subjective dyspnoea in ENS patients may also be explained by this.

In a study published in 2005, Naftali et al. determined that the effectiveness of the conditioning function of the nose was reduced by 23% when the inferior and middle turbinates were removed [230]. One of the causes for disturbed air-conditioning in ENS patients is, as already mentioned, a non-physiological airflow. Whilst in a healthy person the airflow on the turbinate area (diffuser) slows down and is agitated in the middle nasal passage (Figure 11), in the case of ENS, a laminar flow can be seen moving slowly in the upper two thirds of the nose (Figure 12). The airflow behaves in exactly the opposite manner. A static formation of turbulence in inspiration with ENS patients only occurs in the wide-opened maxillary sinuses. Airflow in the maxillary sinus during inspiration with the healthy control group could not be depicted. This proves that the opened maxillary sinus has no share in air-conditioning [231], [232]. An effective mixture of inspired air on the mucosa cannot take place, as there is no microturbulence in the course of the slow laminar flow. This also supports the results of Lindemann's research group [224].

About one third of the temperature and the humidity which are given off to the mucosa via convection during inspiration are extracted from the mucosa again during expiration [233].

Interestingly enough, in the flow simulations significant vortex formation was evident in the choane area, in other words the physiological constriction between the wide nasopharynx and the posterior apertures of nose and the posterior main nasal cavity. This explains the fact that ENS patients complain not only of a dry nose, but also of a dehydration of the pharyngeal mucosae. Normally, expired air coming from the lungs is moist and warm. This air meets a climatic milieu in the nose which is dry and warm. The nose is thus not able to reabsorb the moisture transported from the lungs. The reason for this is the reduced mucosal surface, which does not allow sufficient condensation.

This theory is corroborated by an observation made in the context of flow simulation: in ENS patients, inspired air is accelerated into the rear nasal sections of the nose, i.e. when passing through posterior apertures of nose, and hits the back wall of the nasal pharynx with a higher speed than it would in a healthy person.

Turbulent flows occur with healthy people which, through sideward movement, ensure that laterally flowing particles leave the mucosal surface and centrally flowing particles maintain contact with the mucosa. An intermixing of molecules with higher temperature and molecules with lower temperature occurs, resulting in thermal convection [223].

As explained by the Venturi effect, the flow speed of an incompressible fluid, for example air, changes in direct proportion when it passes through a changing cross-section. The flow speed of air is therefore lowest where the cross-section is widest [234]. An expansion of the nasal cross-section results in a reduction in the speed of flow. This has already been demonstrated in previous rhinological studies [30], [86]. The slow airflow does raise the time contact of air with the mucosa, which at first sight is indicative of a high effectiveness of this physical process. At the same time, a laminar flow takes place at this interface with ENS patients which runs parallel to the surface of the mucosa, and which prevents extensive mixing of flowing air particles.

Normally, an extended contact time leads to sufficient climatisation of air. Keck et al. have referred to this relationship as "subtropical conditions" (alternating warm-moist and cold-dry air conditions), and identified them as optimum conditions for air climatisation of the nose and the deeper respiratory tracts [235].

In the event of an impaired function of the mucosa caused by a reduction of the mucosal surface following removal of the nasal turbinate, a reduction of the water vapour saturation brings about a rise in air temperature accompanied by a reduction of absolute humidity. It is not possible for ENS patients to achieve optimal climatisation of air through the creation of "subtropical" conditions in the nose, and thus to condition it for the tracheal and pulmonary respiratory tracts.

Looking at the shearing forces which appear on the mucosal surface, it can be seen that they are in a linear relationship to the flow speed. When breathing calmly, the pressure of the mucosa is around 1 Pa. Regions where increased shearing forces occur are, for example, the nasal valve region and the anterior sections of the middle turbinate (Figure 13). Elad et al. see a direct connection

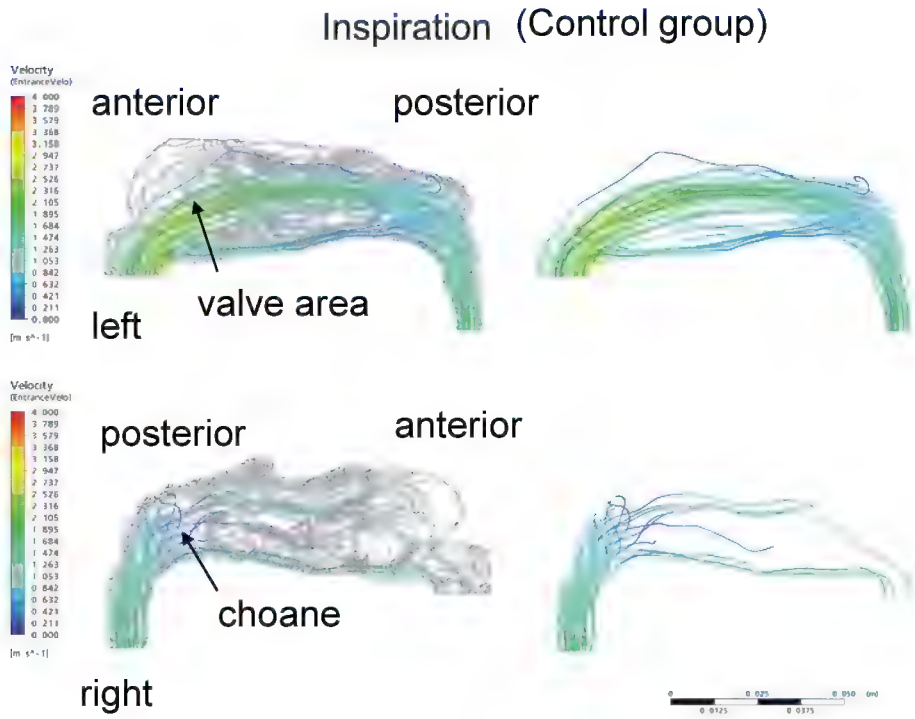

Figure 11: Side-differentiated presentation of flow simulation during inspiration with a representative healthy test person. The volume flow is 200ml/sec. The main flow occurs mainly in the middle section of the nose; the nasal floor and roof of the nose are significantly less strongly flowed through. Turbulence is observed in the nasal valve region and at the posterior apertures of nose.

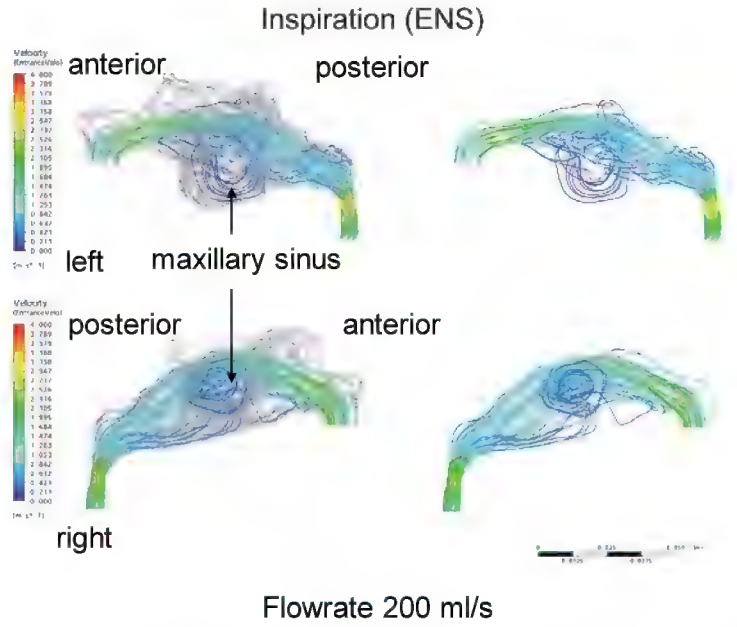

Figure 12: Side-differentiated presentation of flow lines during inspiration with a representative ENS patient. The volume flow is 200 ml/s. The main flow occurs mainly in the upper and middle section of the nose; the nasal floor and the inferior turbinate are less strongly flowed through. Turbulence is observed in the maxillary sinuses.

between the pressure gradients of the shearing forces, the temperature gradient in the nose and the subjective experience of free nasal breathing [229]. As well as on neuronal stimuli such as air temperature and volume, this also depends upon the amount and the functional efficiency of goblet cells in the turbinate mucosa which are triggered by particular pressure conditions and thus determing the secretion of mucous. Studies have demonstrated that mechanical stimuli, such as pressure and shearing forces, can positively modulate the trans-membranous transport within epithelial and endothelial cells [236], [237].

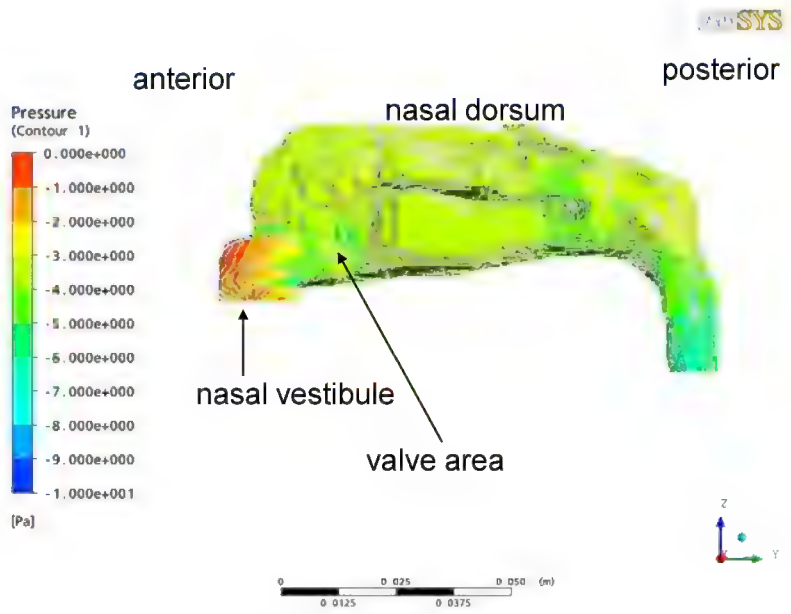

Figure 13: Simulated pressure-profile representation in a healthy subject (pressure measured in Pa).
It can be seen that the highest pressure values on the mucosa are measured at the entrance to the nose and the nasal valve area, and continuously decrease in posterior direction.

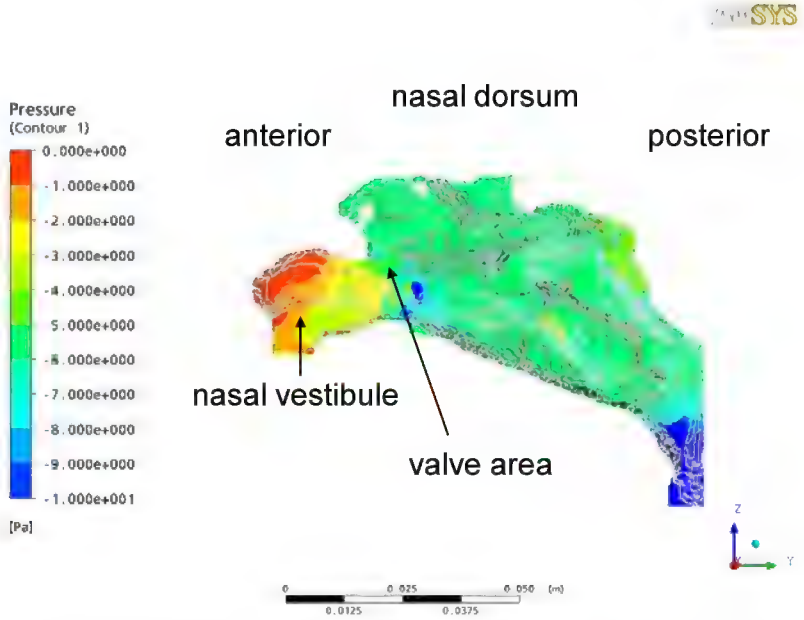

Figure 14: Exemplary simulated pressure-profile representation in an ENS patient (pressure measured in Pa).
It can be seen that the highest pressure values on the mucosa are measured at the entrance to the nose and the nasal valve area, and continuously decrease in posterior direction. The decline of pressure values happens much faster than with the healthy subject. The pressure gradient between anterior and posterior nasal section is higher.

It is accepted that optimum pressure values within narrow limits in healthy people trigger both mucus production in the goblet-cells as well as the ciliary function in order to regulate mucociliary clearance on a cellular level. The precondition for this procedure is a correct balance of pressure values or shearing force on the nasal mucosa [238]. In the case of patients with ENS, these regulation mechanisms are disturbed by altered shearing forces; the pressure profile curves show a more rapid drop on the pressure gradient between the anterior and posterior nasal sections (Figure 14).

The surgical reduction of the nasal cross-section in order to positively influence aerodynamics and to increase airway-resistance does not, however, alter the conditioning function of the nose, which is irreversibly damaged [220]. The reconstruction or transplantion of the missing respiratory mucosa is not possible at present. For this reason, patients profit only to a limited degree from so-called "endonasal augmentation surgery". It has been

reported that at least nasal foetor diminishes; crust formation appears, however, to remain unchanged [218]. As the ENS therapy is unsatisfactory for both patient and doctor, minimal invasive surgery on the turbinate which preserves the mucosa remains one of the most important principles for rhinosurgical therapy.

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